
दृढ़ीकृत कंक्रीट — परीक्षण पद्धतियाँ
भाग 5 दृढ़ीकृत कंक्रीट का अविनाशी परीक्षण
खण्ड 2 कंक्रीट में अलेपित प्रबलित स्टील का अर्ध-सेल विभव
(पहला पुनरीक्षण)

**Hardened Concrete —
Methods of Test**

Part 5 Non-Destructive Testing

**Section 2 Half-Cell Potentials of Uncoated
Reinforcing Steel in Concrete**

(First Revision)

ICS 91.100.30

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FOREWORD

This Indian Standard (Part 5/Section 2) (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

Testing plays an important role in controlling the quality of cement concrete work. Systematic testing of raw materials, fresh concrete and hardened concrete, is an inseparable part of any quality control programme for concrete. This helps achieve a higher efficiency of the materials used and greater assurance of the performance of the concrete, in regard to workability, strength and durability. The test methods used should be simple, direct and convenient to apply. This standard was formulated with this objective in view.

This standard was first published in 1959. In this first revision, it was decided to review and update the various existing test methods of concrete taking into consideration the latest international practices and developments in this field in the country, and also to introduce certain new test methods, wherever required. In the process, the various existing test methods covered in IS 516 : 1959 'Methods of tests for strength of concrete' have been revised considering primarily the corresponding ISO standards while also examining the other best practices world over and in the country. In addition, test methods for determination of additional properties have been included in areas such as permeability, initial surface absorption, corrosion of reinforcement, carbonation of concrete (field test), accelerated carbonation test, and creep of concrete. Also, for better understanding and implementation, some of the other test methods which were spread over in number of other Indian standards have been brought together under the fold of IS 516 as its various parts, such as the splitting tensile strength, ultrasonic pulse velocity test, rebound hammer test, bond in reinforced concrete, and determination of water soluble and acid soluble chlorides. This is with a view to making the standard complete in all respects, and rendering it a comprehensive source of provisions for testing of concrete and reference in other Indian Standards.

In this revision, IS 516 is split into 12 parts. The other parts in the series are:

- Part 1 Determination of strength of hardened concrete
- Part 2 Determination of properties of hardened concrete other than strength
- Part 3 Making, curing and determining compressive strength of accelerated cured concrete test specimens
- Part 4 Sampling, preparing and testing of concrete cores
- Part 6 Determination of drying shrinkage and moisture movement of concrete samples
- Part 7 Determination of creep of concrete cylinders in compression
- Part 8 Determination of modulus of elasticity
- Part 9 Determination of wear resistance
- Part 10 Determination of bond in reinforced concrete
- Part 11 Determination of Portland cement of hardened hydraulic cement concrete
- Part 12 Determination of water soluble and acid soluble chlorides in hardened mortar and concrete

This standard (Part 5/Sec 2) is a newly introduced test method and covers the procedure for measurement of half-cell potential for estimation of corrosion activity of the uncoated reinforcing steel. Influence of various test conditions and some general guidance on the interpretation of test results and data presentation is also covered. The criteria for corrosion condition of rebar in concrete is given for copper and copper sulphate (Cu/CuSO_4) half-cell and the equivalent values for other half cells, namely mercury and mercury chloride (Hg/HgCl_2) and silver – silver chloride (Ag/AgCl) are also given.

(Continued to third cover)

*Indian Standard***HARDENED CONCRETE — METHODS OF TEST****PART 5 NON-DESTRUCTIVE TESTING****Section 2 Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete***(First Revision)***1 SCOPE**

This standard (Part 5/Sec 2) covers the objective, principle, apparatus and test procedure of half-cell potential test method. In addition, influence of test conditions and some general guidance on interpretation of test results are also given. Half-cell potential test usually indicates the level of possibility of the occurrence of reinforcement corrosion as a result of electrochemical action. Subsequent resistivity measurements in zones which are demonstrated to be at risk may indicate the likelihood of corrosion actually occurring. While combination of these methods cannot positively confirm that corrosion has occurred or is occurring, or assess the extent of any corrosion, they represent the most effective non-destructive approach currently available.

NOTES

1 This test method is limited by electrical circuitry. A concrete surface that has dried to the extent that it is a dielectric and surfaces that are coated with a dielectric material will not be an acceptable electrical circuit.

2 No safety concerns have been addressed by this standard and does not profess to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2 OBJECTIVE

Half-cell potential measurements cover the estimation of the electrical half-cell potential/corrosion potential of uncoated reinforcing steel in field and laboratory concrete, for the purpose of determining the corrosion activity of the reinforcing steel. The measurements can be used:

- a) for in-service evaluation and for use in research and development work.
- b) in members regardless of their size or the depth of concrete cover over the reinforcing steel.
- c) may be used at any time during the life of a structure and in any kind of climate provided the temperature is higher than +2 °C.

3 PRINCIPLE

The corrosion potential E_{corr} (half-cell rebar/concrete) is measured as potential difference (or voltage) against a reference electrode (half-cell). The numerical value of the measured potential difference between the steel in concrete and the reference electrode will depend on the type of reference electrode used and on the corrosion condition of the steel in concrete. It is therefore, important to indicate the reference electrode being used for the half-cell potential measurements. Corrosion of a metal implies separate anodic and cathodic processes occurring simultaneously on the same metal surface. Corroding steel in concrete acts as a mixed electrode with coupled anodic and cathodic reactions taking place simultaneously on its surface. At the corroding site (the anode), iron is dissolved and oxidized to iron ions leaving electrons in the steel. Due to the condition of electro neutrality, these electrons have to be consumed by the cathodic reaction at the steel surface, where oxygen is reduced and hydroxyl ions are produced. Depending on the spatial distribution of anodic and cathodic reactions on the surface of the steel and the conductivity of the medium, following two different types of corrosion can take place:

- a) Uniform corrosion, in which anodic and cathodic reactions are coupled to form numerous micro-cells on the steel surface and occur on the same areas.
- b) Macro-cell corrosion or localized corrosion, in which the anodic and cathodic areas of the corrosion process are separated in space with significant potential drop.

4 APPARATUS

The apparatus for half-cell measurement shall consist the following:

- a) Half cell,
- b) Electrical junction device,
- c) Electrical contact solution,
- d) Voltmeter, and
- e) Electrical lead wires.

The basic configuration of the electrical circuit is shown in Fig. 1.

NOTE — While in the figure only one type of half-cell has been specified, that is, the copper-copper sulphate half-cell, others having similar measurement range, accuracy, and precision

characteristics may also be used. In addition to copper-copper sulphate cells, calomel cells or silver-silver nitrate cells have been used in laboratory studies. Potentials measured by other than copper-copper sulphate half cells should be converted to the copper-copper sulphate equivalent potential (*see* Table 1).

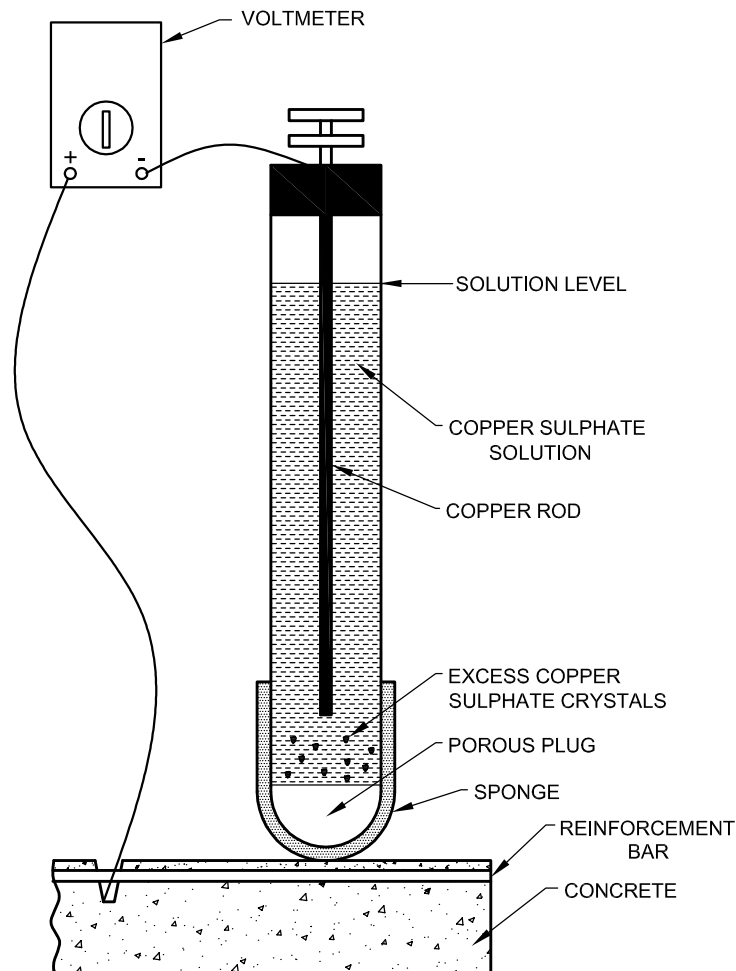


FIG.1 SCHEMATIC OF HALF-CELL POTENTIAL MEASUREMENT

Table 1 Criteria for Corrosion Condition of Rebar in Concrete for Different Half-Cells

(Clauses 4 and 6.11)

SI No.	Cu/CuSO ₄ Electrode	Hg/HgCl ₂ Electrode	Ag/AgCl Electrode	Likely Corrosion Condition
(1)	(2)	(3)	(4)	(5)
i)	> - 200 mV or less negative than - 200 mV	> - 126 mV	> - 106 mV	Low (there is a greater than 90 percent probability that no reinforcing steel corrosion is occurring in that area at the time of measurement)
ii)	- 200 mV to - 350 mV	- 126 mV to - 276 mV	- 106 mV to - 256 mV	Corrosion activity of the reinforcing steel in that area is uncertain
iii)	< - 350 mV or more negative than - 350 mV	< - 276 mV	< - 256 mV	High (there is a greater than 90 percent probability that reinforcing steel corrosion is occurring in that area at the time of measurement)
iv)	< - 500 mV	< - 426 mV	< - 406 mV	Severe corrosion

4.2 Performance of the Assembly of Apparatus

The measurement of half-cell potentials is based on the electrical and electrolytic continuity between rebars in concrete, reference electrode on the concrete surface and voltmeter. Under working temperatures of less than about 10 °C, approximately 15 percent by volume of either isopropyl or denatured alcohol must be added to electrical contact solution to prevent clouding of the electrical contact solution, since clouding may inhibit penetration of water into the concrete to be tested. The rigid tube or container used in half cell composed of a dielectric material that is non-reactive with copper or copper sulphate in case of copper-copper sulphate half-cell, shall have an inside diameter of not less than 25 mm; the diameter of the porous plug shall not be less than 13 mm; the diameter of the immersed copper rod (in case of copper-copper sulphate half-cell) shall not be less than 6 mm, and the length shall not be less than 50 mm. The voltmeter shall have the capacity of being battery operated and have ± 3 percent end-of-scale accuracy at the voltage ranges in use. The input impedance shall be no less than 10 M Ω when operated at a full scale of 0.1 V. The electrical lead wire shall be of such dimension that its electrical resistance for the length used will not disturb the electrical circuit by more than 0.000 1 V.

5 PROCEDURE

5.1 Potential measurements can be performed with a single electrode (point measurements) or with one or several wheel electrodes (potential mapping). The primary goal of potential measurements on reinforced concrete structures is to locate areas of corroding reinforcement. Thus before starting to take measurements a coordinate system has to be put onto the structure in order to be able to relate readings with the point on the structure where they were taken. In homogeneous surface conditions such as wet and dry areas or not embedded re-bars that are encountered should be located on a sketch in order to facilitate the interpretation of potential readings. For a statistical evaluation of the data (cumulative probability plot, histogram) the grid spacing must be kept constant.

5.2 Spacing between measurements shall be consistent with the member being investigated and the intended end use of the measurements (*see Note*).

NOTE — A spacing of 1.2 m has been found satisfactory for evaluation of bridge decks. Generally, larger spacing increases the probability that localized corrosion areas will not be detected. Measurements may be taken in either a grid or a random pattern (coordinates must be recorded as mentioned in 5.1 above even if random pattern is followed). Spacing between measurements should generally be reduced where adjacent readings exhibit algebraic reading differences exceeding 0.15 V (areas of high corrosion activity). Minimum spacing generally should provide at least a 0.1 V difference between readings.

5.3 Electrical connection to the reinforced steel shall be direct electrical connection by means of a compression-type ground clamp, or by brazing or welding a protruding rod to the positive terminal of the voltmeter.

5.4 Electrically connect one end of the lead wire to the half-cell and the other end of this same lead wire to the negative (ground) terminal of the voltmeter.

5.5 After placing half-cell on the concrete surface, the voltmeter reading shall be observed. If the measured value of the half-cell potential does not change or fluctuate with time, pre-wetting the concrete surface is not necessary. However, if the measured value of the half-cell potential changes or fluctuates with time, pre-wetting is required for an amount of time such that the voltage reading is stable (0.02 V) when observed for at least 5 min. In case of pre-wetting no free surface water should remain between grid points when potential measurements are initiated.

5.6 Recording half-cell potential values shall be done to the nearest 0.01 V. Report all half-cell potential values in volts and correct for temperature if the half-cell temperature is outside the range of 22.2 ± 5.5 °C. The temperature coefficient correction of about 0.000 91 V more negative per °C for the temperature range from 0 to 49 °C shall be applied (*see Note*).

NOTE — Present criteria based upon the half-cell reaction of $\text{Cu} \rightarrow \text{Cu}^{++} + 2\text{e}^-$ indicate that the potential of the saturated copper-copper sulfate half-cell as referenced to the hydrogen electrode is -0.316 V at 22.2 °C. The cell has a temperature coefficient of about 0.000 91 V more negative per °C for the temperature range from 0 °C to 49 °C.

6 INTERPRETATION OF RESULTS

6.1 Half-cell potentials are normally interpreted using:

- a) Numeric magnitude technique, or
- b) Potential difference technique, or a combination of the two.

6.1.1 Numeric Magnitude Technique

Laboratory testing (partial immersion in chloride solutions) and outdoor exposure (including chloride exposure) of various reinforced concretes above-ground in an area in which the precipitation rate exceeded the evaporation rate, indicate the potential values and the likely corrosion condition is given in Table 1.

NOTE — These criteria shall not normally be utilized under the following conditions unless either experience or destructive examination of some areas, or both, suggest their applicability:

- a) To evaluate reinforcing steel in concrete that has carbonated to the level of the embedded steel,
- b) To evaluate indoor concrete that has not been subjected to frequent wetting unless it has been protected from drying after casting,
- c) To compare corrosion activity in outdoor reinforced concretes of highly variable moisture or oxygen content, or both, at the embedded steel, and

- d) To formulate conclusions concerning changes in corrosion activity with time on a rehabilitated structure in which the rehabilitation caused the moisture or oxygen content, or both, at the embedded steel to change with time (for example, installation of a low permeability overlay or waterproof membrane on a chloride-contaminated bridge or parking deck).

6.1.2 Potential Difference Technique

Where large areas of electrically interconnected, embedded steel exist, for example, in bridge decks, reinforced columns, or beams, careful measurement of potentials in a closely spaced grid pattern and the subsequent plotting of equipotential contour maps may allow identification of high versus low corrosion rate areas.

NOTE — Half-cell potentials may or may not be an indication of corrosion current. Half-cell potentials may in part or in whole reflect the chemistry of the electrode environment. For example, increasing concentrations of chloride can reduce the ferrous ion concentration at a steel anode, thus lowering (making more negative) the potential. Unless such chemistry, and the presence or absence of competing electrode reactions, is known, a half-cell potential should not be interpreted as indicative of corrosion rate, or even as indicative of a corrosion reaction.

6.1.3 The data may also be presented in terms of equipotential control map, etc (see Annex A for guidance).

7 CALIBRATION, STANDARDIZATION AND PRECISION

7.1 Care of the Half Cell

7.1.1 The porous plug shall be covered when not in use for long periods to ensure that it does not become dried to the point that it becomes a dielectric. If cells do not produce the reproducibility or agreement between cells described in 7.1.2 and 7.1.3 cleaning the rod in the half cell may rectify the problem. In case of copper rod, the rod may be cleaned by wiping it with a dilute solution of hydrochloric acid. The solution used shall be renewed either monthly or before each use, whichever is the longer period. At no time shall steel wool or any other contaminant be used to clean the copper rod or half-cell tube.

7.1.2 The difference between two half-cell readings taken at the same location with the same cell should not exceed 0.01 V when the cell is disconnected and reconnected.

7.1.3 The difference between two half-cell readings taken at the same location with two different cells should not exceed 0.02 V.

8 REPORT

Report the following information:

- a) Date/period of testing.
- b) Details about whether carried out *in-situ* or in laboratory.
- c) Details of the structure/member being tested and visual indications of corrosion of steel, if any.
- d) Details of concrete (age, grade, etc).
- e) Details of half-cell measurement:
 - 1) Type of cell used if other than copper-copper sulphate.
 - 2) The estimated average temperature of the half-cell during the test.
 - 3) The method for pre-wetting the concrete member and the method of attaching the voltmeter lead to the reinforcing steel.
 - 4) An equipotential contour map, showing the location of reinforcing steel contact, or a plot of the cumulative frequency distribution of the half-cell potentials, or both.
 - 5) The percentage of the total half-cell potentials that are more negative than -0.35 V for Cu/CuSO_4 electrode (-0.276 V for Hg/HgCl_2 and -0.256 V for Ag/AgCl electrodes respectively).
 - 6) The percentage of the total half-cell potentials that are less negative than -0.20 V for Cu/CuSO_4 electrode (-0.276 V for Hg/HgCl_2 and -0.256 V for Ag/AgCl electrodes respectively).

ANNEX A

(Clause 6.1.3)

DATA PRESENTATION

A-1 Test measurements may be presented by one or both of two methods. The first, an equipotential contour map, provides a graphical delineation of areas in the member where corrosion activity may be occurring. The second method, the cumulative frequency diagram, provides an indication of the magnitude of affected area of the concrete member.

A-1.1 Equipotential Contour Map

The map providing a graphical delineation of areas in the member where corrosion activity may be occurring, is a plot of the locations of the half-cell potential values of the steel in concrete and draw contours of equal potential through points of equal or interpolated equal values. The maximum contour interval shall be 0.10 V. An example is shown in Fig. 2.

A-1.2 Cumulative Frequency Distribution

It is a graph providing an indication of the magnitude of affected area of the concrete member. To determine the

distribution of the measured half-cell potentials for the concrete all half-cell potentials are ranked from least negative potential to greatest negative potential. The plotting position of each numbered half-cell potential is determined in accordance with the following equation:

$$f_x = \frac{r}{\Sigma n + 1} \times 100$$

where

f_x = plotting position of total observations for the observed value, percent,

r = rank of individual half-cell potential, and

Σn = total number of observations.

After plotting the half-cell potentials, draw a line of best fit through the value (*see Note*). An example of a completed plot is shown in Fig. 3.

NOTE — It is not unusual to observe a break in the straight line. In these cases, the line of best fit shall be two straight lines that intersect at an angle.

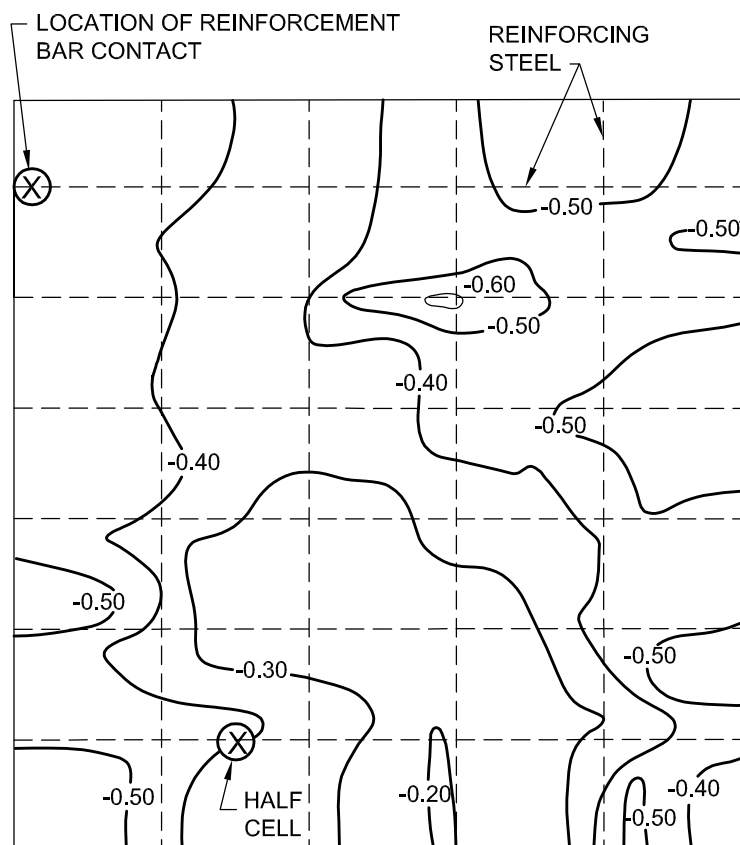


FIG. 2 EQUIPOTENTIAL CONTOUR MAP

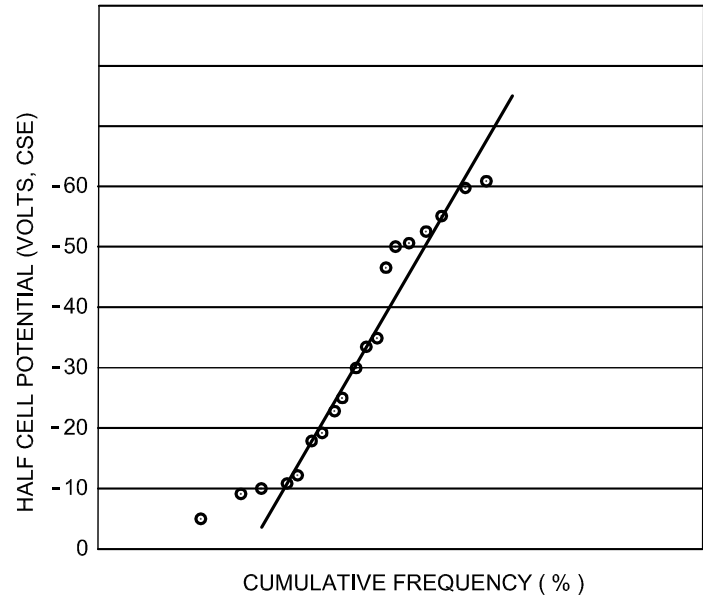


FIG. 3 CUMULATIVE FREQUENCY DIAGRAM

ANNEX B*(Foreword)***COMMITTEE COMPOSITION**

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Panel for Revision of Indian Standards on Test Methods for Concrete, CED 2:2/P7

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(Continued from second cover)

In view of the limitations of each method of non-destructive testing of concrete, it is essential that the results of tests obtained by one method should be complemented by other tests and each method should be adopted very carefully.

In the formulation of this standard, assistance was derived from ASTM C 876-15 'Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete' and RILEM TC 154 EMC 'Electrochemical techniques for measuring metallic corrosion in concrete'.

The composition of the committee responsible for the formulation of this standard is given in Annex B.

In reporting the result of a test or analysis made in accordance with this standard, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that specified value in this standard.

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